# A new family dependent interaction in Tevatron top dilepton candidate events ?

J. L. Diaz-Cruz[1]
[1] *Cuerpo Académico de Particulas, Campos y Relatividad FCFM, BUAP, Ap.Postal 1364 Puebla Pue. 72000, Mexico*

C. E. Pagliarone[2]
[2] *Universitá degli Studi di Cassino & I.N.F.N. Pisa, via F. Buonarroti n. 2 - 56127 Pisa, Italy.*

New family dependent fermionic interactions have been conjectured in several extensions of the Standard Model that range from Supersymmetry to composite theory up to flavor interactions. Strong constraints on these theoretical scenarios can be derived from light fermion phenomenology and from $B$-mesons studies. Corresponding constrains on the top quark sector are, on the other hand, rather week. Tevatron data, on top quark pair production and decay in dilepton channel, may suggest some deviation from the Standard Model expectations. Such a deviation can be successfully re-interpreted in terms of an exotic top decay that can arise in several theories beyond the Standard Model. Further investigations at present and future colliders will provide crucial tests on the models under discussion.

PACS numbers: 14.65.Ha,12.60.-i



## I. INTRODUCTION

After the discovery of the top quark at Fermilab Tevatron Collider [1, 2], experimental attention has been turned on the examination of its production mechanisms and decay properties. Within the Standard Model (SM), the top quark production cross section is evaluated with an uncertainty that is of the order of $\sim$ 15% and top quarks are assumed to decay to a $W$ boson and a $b$ quark almost 100% of the time. In the fermion sector of the SM, plenty of experimental data, have proved that interactions of quarks and leptons, with gauge bosons, are correctly described by the $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge theory [3]. At tree-level, SM neutral interactions are diagonal in flavor space, however, due to the generation mixing, that appears in the charged currents, flavor changing neutral currents (FCNC) can arise at loop level. The fact that FCNC $B$-meson decays have been already detected, at rates consistent with the SM [4], represents a great success for the model itself. Current bounds, on rare decays of light quarks and leptons, impose further constraints on new sources of FCNC transitions. However, SM predictions for related processes, involving top quarks, are strongly suppressed, although corresponding experimental bounds are rather weak.

Due to its exceedingly heavy mass, it is reasonable to expect the top to be more related to new physics than other fermions. Top quark physics may then serve as an important window for probing physics beyond the SM. A significant deviation from SM prediction would then indicate either a novel production mechanism or a novel decay channel that is the subject of the present paper. As matter of fact, it could be even possible that such effects may be observed at present Tevatron collider experiments (CDF-II, D0) or in the next generation collider experiments at LHC [5] or later on at the next Linear Collider [6]. FCNC top quark decays, such as $t \to c\gamma$, $t \to cg$, $t \to cZ$ and $t \to c\phi$ have been studied, for some time, as possible signals of physics beyond the SM [7]. The extended models, that we are interested to discuss, in the present article, include both top-charm (TC) transitions and $\mu-\tau$ violating (MTV) interactions, whose combined effect can induce top quark decays such as $t \to c\tau\mu$ or $t \to u\tau\mu$. Such processes may arise either through a scalar bosons, with family-dependent couplings, or by direct contact interactions. We shall refer to $t \to c(u)\tau\mu$ as double flavor-violating (DFV) top decays.

## II. THEORETICAL MOTIVATIONS

Past and present Tevatron top analysis have been performed, always assuming, a dominant SM branching ratio ($Br(t \to bW) \simeq 1$). The possibility that exotic top quark decay modes could affect the dilepton top quark events ($p\bar{p} \to t\bar{t} \to W^+bW^-\bar{b} \to b\ell^+\nu_\ell\bar{b}\ell^-\bar{\nu_\ell}$) have not been considered yet. In this paper, we are interested in studying how the dilepton signature, could be affected when one includes additional top decay channels such as: $t \to c\tau\mu$ or $t \to u\tau\mu$. We will argue later that such an effect could have already shown up and may be available in the top quark data published by the CDF collaboration [8],[9].

Since in the SM, the branching ratio of top decaying into $c(u)\mu\tau$ is extremely suppressed [10, 11], then the study of this decay channels may be an excellent way for searching for physics beyond the SM. In the next sections we will discuss the expected branching ratios arising in several and well motivated extensions of the SM, which have been proposed to tackle some open issues.

Among these theories, we shall discuss first Supersymmetry (SUSY), which is studied mainly in connection with a possible solution of the hierarchy problem [12]. Its minimal incarnation, the Minimal Supersymmetric

extension of the SM (MSSM), has well know attractive features, such as allowing gauge coupling unification, and explaining electroweak symmetry breaking (EWSB) as a radiative effect, driven by the large top quark Yukawa coupling. In addition SUSY also predicts tau-bottom Yukawa unification and provides a dark matter candidate. Within the context of SUSY models, it is possible to induce FCNC Higgs interactions, which could mediate the MTV top decay $t \to c\mu\tau$

The resulting structure of the Higgs-Yukawa sector in MSSM, corrected by loop effects, actually shares similarities with the general version of the two-Higgs doublet model (THDM-III), whose predictions for DFV top decays will be discussed, for comparison, with other models. The Yukawa structure of the THDM-III relies on the assumption of a specific texture, for fermion mass matrices, which makes possible to derive a pattern for TC and MTV interactions, which is possible to constrain with low-energy physics experiments, making also available predictions at higher energy [13]. A particular successful ansazt, for the THDM-III, consists in assuming a four-texture for the mass matrices, which is able to reproduce quark and charged lepton masses, as well as the CKM mixing matrix. This approach can be considered as an starting point to address one of the most challenging problems of the SM, the flavor problem, namely, how to explain the observed pattern of quark and lepton masses and their mixing angles.

Along the lines of flavor physics, we are also going to discuss models that attempt to explain the structure of the fermion mass matrices by an approximate flavor symmetry. Models, with either Abelian or non-Abelian flavor symmetry, have been proposed in literature [14]. The scale, associated with these models, could range from TeV up to the Grand Unification scale (GUT scale). Flavor Models, with a low scale flavor symmetry breaking, offer a possibility to observe direct effects of flavor physics, for instance through the detection of scalar particle associated with the mechanism of flavor symmetry breaking, the so called *Flavon Fields*. On the other hand, when the flavor symmetry is a global-type symmetry, its breaking leaves a light pseudo-goldstone bosons, the *familons* that could provide detectable signatures too [15]. The effects of the flavons or familons could even be transmitted to the EWK Higgs sector, through mixing [16], and could induce exotic Higgs bosons and top quark decays.

Finally we shall also consider strongly interacting scenarios [17]. These models are interesting as they offer some clue about the nature of EWSB. As matter of fact, such models often predict new physics to manifest itself in the top quark sector mainly because of the large top-quark mass. They can also arise because of the presence of additional substructure layers, which could manifest themselves first for the heaviest SM fermion. Strong interaction scenarios could then induce exotic DFV top quark decays too.

## III. TC AND MTV MODELS

### A. Overview

In order to search for effects of a new family-dependent interaction (FDI), in top quark decays, we will start considering first the case when such interaction is mediated by a new boson ($S^0$). The case, where such decays occurs through an unsuppressed contact interaction, will be discussed separately. The interactions of $S^0$ is here described by an effective lagrangian, that parametrizes family-dependent couplings for quarks and leptons, $q, l_{L,R}$, in terms of form factors: $F^{q,l}_{L,R}$. For the top-charm and tau-muon couplings the lagrangian takes the following form:

$$\mathcal{L} = S^0\bar{t}[F^u_L P_L + F^u_R P_R]c + S^0\bar{\tau}[F^l_L P_L + F^l_R P_R]\mu + h.c. \quad (1)$$

In the present case, the top quark decay $t \to c\mu\tau$ will proceed through the $S^0$ intermediate state, namely $t \to cS^0$ and then $S^0 \to \mu\tau$.

### B. TC and MTV in Minimal SUSY Models

Within the context of the MSSM, we shall consider that the double flavor-violating (DFV) top quark decays $t \to c\mu\tau$ are mediated through TC and MTV Higgs interactions, which arise through loops involving gauginos and sfermions. In particular, lepton flavor violation (LFV), experimentally observed in the neutrino sector [18], could be transmitted from the SUSY breaking sector to sfermions, and then from the sfermions to the Higgs sector. In this way the tree-level type-II Higgs sector of MSSM becomes a type-III THDM. Thus, LFV Higgs interactions in MSSM, which induce decays such as $\phi_i \to \mu\tau$ ($\phi_i = h, H, A$), are produced by loops involving sleptons and charginos or neutralinos [19]. Moreover, because SUSY GUT's relate quarks and leptons, it is possible that the large mixing, observed in the neutrino sector, implies a large mixing in the up-type squarks, which in turn, could also induce the FCNC top decay $t \to ch^0$ [20]. By combining these effects it is possible to have exotic top quark decay $t \to ch^0$, followed by $h^0 \to \mu\tau$.

We shall consider a minimal SUSY-FCNC schemes, where a large mixing appears in the slepton and squark trilinear $A$-terms [20]. In particular we will consider that the elements of $A$-terms satisfy the conditions: $A_{33} = A_0$,$A^u_{23} = x_u A^u_0$, $A^l_{23} = x_l A^l_0$, where $x_{u,l}$ are unknown $O(1)$ parameters, $A_0$ denotes an universal SUSY breaking trilinear term and the remaining $A$-entries are assumed to vanish. After diagonalizing the resulting sfermion mass matrices, and writing the interactions in terms of mass eigenstates, one can evaluate the TC/MTV top and Higgs decays. The branching ratios will be sensitive to the values of $x_{u,l}$, since these parameters affects both the sfermion mass-eigenvalues (that enter the loop integrals) and the TC/MTV couplings in the $\tilde{t}-\tilde{c}$ and $\tilde{\mu}-\tilde{\tau}$ sectors.

### C. TC and MTV interactions in the THDM-III

The THDM-III, based on the assumption of a specific four texture for the fermion mass matrices, has been extensively discussed in Ref. [13]. In that paper we derived the resulting pattern for TC and MTV Higgs interactions, which generalizes the Cheng-Sher ansazt [21]; namely the phases allowed by the hermitian four-texture ansazt were also included in the analysis. We derived also constraints on the model parameters, by comparing low-energy physics processes (mainly: $\mu \to e + \gamma$, $\tau \to 3\mu$, $e - \mu$ conversion and rare $B$-decays). This allowed us to make predictions on the detectability of MTV Higgs decays at present and higher-energy colliders [22].

In this model, the couplings, of the lightest Higgs boson ($h^0$) with fermions of different flavor, can be written as follows:

$$\mathcal{L}_{hf_if_j} = \frac{\sqrt{m_i m_j}}{v} \tilde{\chi}_{ij} \eta_h \bar{f}_i f_j h^0 \tag{2}$$

where $m_{i,j}$ corresponds to the masses of the $i$ and $j$ fermions, $v$ denotes the scale of EWSB and $\tilde{\chi}_{ij}$ are unknown $O(1)$ coefficients. The factor $\eta_h$ depends on the fermion type. For $u$-type quarks its value is: $\eta_h = -\cos(\beta-\alpha)/2\sqrt{2}\sin\beta$, while for $d$-type quarks and leptons: $\eta_h = \cos(\beta-\alpha)/2\sqrt{2}\cos\beta$, where $\alpha$ denotes the mixing angle in the $CP$-even Higgs sector. Therefore, the form factors for the couplings $h^0 f_i \bar{f}_j$ are: $F_L = F_R = \sqrt{m_i m_j}\chi^{u,l}_{23}\eta_h/v$.

### D. Flavored bosons and TC/MTV top decays

Models with a low flavor scale, which offer the possibility to observe direct flavor physics effects, could also predict large rates for the decay: $t \to c\mu\tau$. One way to mediate this decay can be provided by the scalar particle responsible for the flavor symmetry breaking, the so called *flavon fields* ($\Phi^0_F$). In this case, we shall consider a model that contain a scalar particle that couples to fermions of different generations. A convenient parametrization, for its couplings, is provided by the Cheng-Sher ansazt [21]. In order to maximize the effects, in the following analysis, we shall assume a scenario where the flavon field couples predominantly to fermions of different generations. Such a pattern can arise when flavor symmetry is non-abelian [15]. Then, we assume that the mass-eigenstate $S^0$ results form the mixing between a flavon field $\Phi^0_F$ and a Higgs boson $H^0$. The form factors for the coupling $S^0 f_i \bar{f}_j$ are:

$$F_L = F_R = \sqrt{m_i m_j}\frac{\chi_{ij}}{v}[(1-\delta_{ij})\sin\xi + \cos\xi\delta_{ij}] \tag{3}$$

where $m_{i,j}$ correspond to the masses of the fermion $i$ and $j$, $v$ denotes the v.e.v., that breaks the electroweak symmetry, and $\xi$ is the angle that parametrizes the mixing between the Higgs and the flavon fields, in the scalar sector. The factor $\chi_{ij}$ is again an $O(1)$ unknown coefficient.

### E. Strong Dynamics

Furthermore, because the top quark is the heaviest SM fermion, it could offer some clue about the nature of EWSB, or could even be a composite state. In any case, it is likely that strong dynamics could induce rare top quark decays too. In this case, the strong dynamics could be associated with models of composite quarks and leptons and it is possible to have contact interactions, that can also mediate exotic transitions. The contact interaction for $tc\tau\mu$, including only a scalar or a pseudoscalar coupling, is given by:

$$\mathcal{L} = \frac{c_{23}}{\Lambda^2}\,\bar{t}\,\Gamma_S\, c\bar{\tau}\,\Gamma'_S\,\mu + h.c. \tag{4}$$

where $c_{23}$ is an unknown coefficient that has been calculated to be about $m_t^2/96\pi$ [23] and $\Gamma_s = 1(\gamma_5)$ for scalar (pseudoscalar) couplings.

## IV. RESULTS ON DFV TOP $\mathbf{Br(t \to c\tau\mu)}$

We are now interested in the evaluation of the double-flavor-violating top decay Branching Ratios, $Br(t \to c\mu\tau)$, for all the models discussed above. When this decays are mediated by the scalar resonance $S^0$, we can factorize the branching ratio as follow:

$$Br(t \to c\tau\mu) = Br(t \to cS^0) \times Br(S^0 \to \mu\tau) \tag{5}$$

where $Br(t \to cS^0) = \Gamma(t \to cS^0)/\Gamma_t$. For the total top decay width, we will use the approximation: $\Gamma_t = \Gamma(t \to bW^+)_{\rm SM}$ and $Br(S^0 \to \mu\tau) = \Gamma(S^0 \to \mu\tau)/\Gamma_S$. At this point the total width of the scalar will depend only from the model. The decay widths for $t \to cS^0$ and $S^0 \to \mu\tau$ are then written in terms of form factors ($F_{L,R}$) as follows:

$$\Gamma(t \to cS^0_i) = \frac{m_t}{16\pi}(1-\frac{m_h^2}{m_t^2})^{1/2}[|F^t_L|^2 + |F^t_R|^2] \tag{6}$$

$$\Gamma(S^0\tau\mu) = \frac{M_S}{8\pi}[|F^l_L|^2 + |F^l_R|^2] \tag{7}$$

We find the following results for each of the model considered.

**1. MSSM**. In the case of the MSSM, the DFV decay $t \to cS^0$ followed by $S^0 \to \mu\tau$ is always kinematically allowed for $S^0 = h^0$. Then, as shown in table 1, the decay branching ratio $Br(t \to ch^0)$ can be as large as $10^{-3} - 10^{-4}$, over a large part of the SUSY parameter space, where the mass of the lightest Higgs boson $h^0$ is around $110 \div 130\,GeV$ [20]. For a gluino mass: $M_{\tilde{g}} =$ 500 GeV, pseudo-scalar Higgs mass: $m_A = 300$ GeV, SUSY parameters $(\tilde{m}, \mu, A_u) = (0.6, 0.3, 1.5)$ TeV, $x_u = 0.9$, $\tan\beta = 5\,(10)$, one finds: $Br(t \to ch^0) = 4.0 \times 10^{-4}\,(10^{-3})$. Similarly, one can evaluate the decay $h \to \mu\tau$, and finds a branching ratio of the order of $10^{-4} \div 10^{-5}$ [19]. In fact, for a Bino-mass $m_{\tilde{B}} = 600$ GeV, $(\tilde{m}, \mu, A_l) = (0.6, 0.3, 0.3)$ TeV, $x_l = 0.9$ and $\tan\beta = 5(10)$ we get: $Br(h^0 \to \mu\tau) = 4.4 \times 10^{-4}(1.2 \times 10^{-4})$.

| $\mathbf{M_A}$ | $\mathbf{M_{\tilde{g}}}$ | $\mathbf{\tan\beta = 5}$ ($\times 10^{-5}$) | | $\mathbf{\tan\beta = 20}$ ($\times 10^{-5}$) | | $\mathbf{\tan\beta = 50}$ ($\times 10^{-5}$) | |
|---|---|---|---|---|---|---|---|
| 150 | 250 | 1.1 | 57 | 1.9 | 200 | 2.1 | 260 |
| 150 | 500 | 0.9 | 33 | 1.4 | 95 | 1.6 | 120 |
| 300 | 250 | 1.4 | 69 | 2.0 | 210 | 2.1 | 260 |
| 300 | 500 | 1.1 | 40 | 1.5 | 99 | 1.6 | 120 |
| 600 | 250 | 1.4 | 70 | 2.0 | 210 | 2.1 | 270 |
| 600 | 500 | 1.1 | 41 | 1.5 | 100 | 1.6 | 120 |

TABLE I: $Br(t \to c\,h^0)$ for a sample set of $A1$-type inputs with $(\tilde{m}0, \mu, A_0^u) = (0.6,\ 0.3,\ 1.5)\,TeV$. The two numbers in each entry correspond to $x = (0.5,\ 0.9)$, respectively. $m_A$ and $m_{\tilde{g}}$ are expressed in $GeV$.

Therefore the branching ratio for the DFV top quark decay $t \to c\mu\tau$ reaches a value of the order $2 \times 10^{-7}$ for $\tan\beta = 5(10)$, which is well bellow present top analysis sensitivity.

**2. The THDM-III**. For the THDM-III we have that low energy physics implies that $\chi^l_{23}$ is constrained to be of order $10^{-1}$, while $\chi^u_{23}$ remains essentially unconstrained. Therefore, we can take it of order one. For $m_h = 120$ GeV, and $5 < \tan\beta < 50$, $\alpha = \beta - \pi/3$, it is possible to obtain: $\chi^l_{23} = 0.1$, and $Br(h^0 \to \mu\tau)$ only gets up to about $2 \times 10^{-5}$, while for the TC top decay we find: $Br(t \to ch^0) \simeq 0.1$. Then, for DFV top decay, we calculate: $Br(t \to c\mu\tau) = 2 \times 10^{-6}$. It should be pointed out that low values for $Br(h^0 \to \mu\tau)$ are obtained in this model, because its flavor structure forces the coefficients to satisfy the condition: $\chi^l_{23} = \chi^l_{13}$, which then allows to use the rare decay $\mu \to e\gamma$ to constrain the parameter. When this relation no longer holds, it is possible to have: $\chi^l_{23} \simeq 1$, and then this makes possible to obtain: $Br(h^0 \to \mu\tau) \simeq 4 \times 10^{-2}$, and therefore: $Br(t \to c\mu\tau) = 4 \times 10^{-3}$.

**3. Flavon-Higgs Mixing Model**. The result for the branching ratio will depend on the mixing angle $\xi$, introduced to parametrize the mixing between the Higgs and flavon fields. We shall assume that the lightest mass-eigenstate, which is denoted by $S^0$, has mass in the intermediate range: $m_Z < m_S < m_t - m_c$. Then, in order to compute its branching ratio, we shall approximate it as: $Br(S^0 \to \mu\tau) = \Gamma(S^0 \to \tau\mu)/\Gamma(S^0 \to b\bar{b})$. For a reasonable range of parameters, $\sin\xi = 0.9$, $m_S = 120$ GeV, we find that $Br(t \to cS^0) \simeq 0.1$, $Br(S^0 \to \mu\tau) \simeq 0.4$, therefore $Br(t \to c\mu\tau) \simeq 0.04$. As the parameters $\chi^l_{23}$ and $\xi$ are essentially unconstrained, larger values for $Br(t \to c\mu\tau)$ around 0.1, are also achievable in this model.

**4. Strongly Interacting Model**. In this scenario, there is a contact interaction that induces directly the decay $t \to c\mu\tau$, with a partial width given by:

$$\Gamma(t \to c\tau\mu) = \frac{1}{96\pi}\frac{m_t^5}{\Lambda} \qquad (8)$$

Since there are no constraints on such operators, one can even have $\Lambda \simeq m_t$, which then gives a branching fraction for DFV top decay of order of $\simeq 0.1 \div 0.2$. A summary of all the results found is shown in Table II.

## IV. MTV INTERACTIONS AND $\mathbf{t\bar{t} \to b\ell^+\nu_\ell\bar{b}\ell^-\bar{\nu}_\ell}$

### A. Overview

Within the SM, a top, with a mass above $Wb$ threshold, is predicted to have a decay width dominated by the two-body process: $t \to Wb$ ($Br \simeq 0.998$) [4]. A $t\bar{t}$ pair will then decay via one of the following channels, classified according to the final state: *i*) *Dilepton*, where both $W$ decays are leptonic ($\ell_W$), with 2 jets arising from the two $b$-quark hadronization and missing transverse energy ($\not\!\!E_{\mathrm{T}}$) coming from the undetected neutrinos [24]: $Br(e,e) = Br(\mu,\mu) = Br(\tau,\tau) \simeq 1/81$, $Br(e,\mu) = Br(e,\tau) = Br(\mu,\tau) \simeq 2/81$; *ii*) *Lepton+jets*, where one $W$ decays leptonically and the other one into quarks, with 4 jets and $\not\!\!E_{\mathrm{T}}$: $Br(e{+}jets) = Br(\mu{+}jets) = Br(\tau + jets) \simeq 12/81$; *iii*) *All-hadronic*, where both the $W$'s decay into quarks with 6 jets and no associated $\not\!\!E_{\mathrm{T}}$: $Br(jets) \simeq 36/81$. A $\tau$, coming from $W$, will then decay either in $e\overline{\nu}_e\nu_\tau$ or $\mu\overline{\nu}_\mu\nu_\tau$ ($\tau_\ell$) or in a narrow jet ($\tau_h$), with branching ratios that are: $\Gamma^\tau(\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma^\tau_{total} = 0.1736 \pm 0.006$, $\Gamma^\tau(e^-\overline{\nu}_e\nu_\tau)/\Gamma^\tau_{total} = 0.1784 \pm 0.006$ and $\Gamma^\tau(\tau \to jet)/\Gamma^\tau_{total} \simeq 0.64$ [4]. Then $\tau$'s coming from $t\bar{t}$ decay will give rise to the following final states: $\not\!\!E_{\mathrm{T}}\tau_h\tau_h b\bar{b}$, $\not\!\!E_{\mathrm{T}}\tau_h\tau_\ell b\bar{b}$, $\not\!\!E_{\mathrm{T}}\tau_{\ell'}\tau_\ell b\bar{b}$, $\not\!\!E_{\mathrm{T}}\ell_W\tau_h b\bar{b}$ and $\not\!\!E_{\mathrm{T}}\ell_W\tau_\ell b\bar{b}$. Further on, we will call dilepton only the following final states: $ee + X$, $e\mu + X$ or $\mu\mu + X$.

In both CDF Run 1 and Run 2 $t\bar{t}$ dilepton analysis, events were selected by requiring two opposite sign (OS) high-$P_T$ leptons with $P_T^\ell > 20\ GeV/c$ ($|\eta^\ell| < 1.0$), at least two jets with measured $E_T^{jet} > 10\ GeV$ ($|\eta^{jet}| < 2.0$), and $\not\!\!E_{\mathrm{T}} > 25\ GeV$. To ensure that the $\not\!\!E_{\mathrm{T}}$ is not due to mismeasurements, events were also required to have $\not\!\!E_{\mathrm{T}} > 50\ GeV$, if the azimuthal angle between the direction of $\overrightarrow{\not\!\!E_{\mathrm{T}}}$ and the nearest lepton or jet was less than $20^0$. In order to enhance the purity of the sample a further cut was applied; $H_T$, the scalar sum of $P_T^\ell$, $E_T^{jet}$ and $\not\!\!E_{\mathrm{T}}$, was required to exceed 170 (200) $GeV$ in Run 1 (Run 2) analysis [8, 9]. Using $109 \pm 7\ pb^{-1}$ of Run 1 data, CDF found, in total, 8 events: 0 $ee$, 1 $\mu\mu$ and 7 $e\mu$ when, for example, 3.2 events was expected (top plus SM background [25]) in the $e\mu$ channel [8]. In Run 2, using 193 $pb^{-1}$ of data, CDF-II observed 13 events: 1 $ee$, 3 $\mu\mu$ and 9 $e\mu$ when the expected numbers, scaled to 13, are $3.3 \pm 0.5$, $2.8 \pm 0.5$ and $6.8 \pm 0.8$ [9]. An excess in the $e\mu$ channel and a deficit in the $ee$ channel have been found in both Run 1 and Run 2 counting experiments. We believe that this asymmetry does not look easy to explain simply in terms of different efficiencies, acceptances and backgrounds for the three classes of events.

| MODELS | $\mathbf{Br(t \to cS^0)}$ | $\mathbf{Br(S^0 \to \mu\tau)}$ | $\mathbf{Br(t \to c\mu\tau)}$ |
|---|---|---|---|
| **MSSM** | $10^{-3} - 10^{-4}$ | $10^{-4} - 10^{-5}$ | $10^{-7} - 10^{-9}$ |
| **Flavon** | $1. \times 10^{-1}$ | $4. \times 10^{-1}$ | $4. \times 10^{-2}$ |
| **THDM-III** | $10^{-1}$ | $2 \times 10^{-5}$ | $2 \times 10^{-6}$ |
| **Strong Dynamics** | – | – | $0.1 \div 0.2$ |

TABLE II: Branching ratios for $t \to cS^0$, $S^0 \to \tau\mu$ and for $t \to c\mu\tau$. In models with strong dynamics, DFV decays proceed through a direct contact interaction.

### B. Model Independent Parametrization

In the context of the previously discussed theoretical scenarios, MTV top decay $t \to c\mu\tau$ are available with branching ratios up to 0.2. $Br(t \to u\tau\mu)$ is generally suppressed, except for the case of strongly interacting model, where both the branching ratios may reach similar values. If $\mathcal{B}$ is the branching ratio for MTV top decays: $\mathcal{B} \equiv Br(t \to c(u)\mu\tau)$ and we assume no other significatively accessible decay channels, either than the SM and the MTV itself: $Br(t \to Wb) = 1-\mathcal{B}$. The possible decay modes for a $t\bar{t}$ pair are then: *i)* purely SM decays occuring with a branching ratio of $(1-\mathcal{B})^2$; *ii)* mixed SM-MTV decays accessible with a branching ratio of $2\mathcal{B}(1-\mathcal{B})$; *iii* purely MTV top decays having a branching ratio of: $\mathcal{B}^2$. In total $(1-\mathcal{B})^2 + 2\mathcal{B}(1-\mathcal{B}) + \mathcal{B}^2 = 1$. Then SM-MTV $t\bar{t}$ decays, with one leg decaying into $bW_\ell$ and the other one into $c\mu\tau_h$, may fake the SM dilepton signature.

We found that a $\mathcal{B} \simeq 0.10 \div 0.25$ is able to provide an excess in the $e\mu$ channel and a deficit in the number of $ee$ events that is consistent with CDF Run 1 and Run 2 data. Anyhow, we believe that, at the present, dilepton analysis cannot rule out any of the model studied in present paper.

## V. CONCLUSIONS AND PERSPECTIVES

Triggered by CDF top dilepton analysis, that observed an excess in the number of $e\mu$ and a deficit in the number of $ee$ top dilepton candidates, we studied the possibility that double flavor-violating top decays: $t \to c(u)\tau\mu$ may contaminate the top sample. If MSSM predicts values for $Br(t \to c\tau\mu)$ up to about $10^{-7}$ and Flavor Models gives $\simeq 4 \times 10^{-2}$, Strongly Interacting Models offer the possibility to reach $\simeq 0.10 \div 0.20$. We found that such a value can explain the pattern observed in the data. As at present, top dilepton analysis cannot rule out any of the model discussed above, further studies will be needed in order to determine whether such new physics effects will be confirmed at Tevatron or may show up at lower branching ratios in next coming LHC experiments.

## ACKNOWLEDGMENTS

This work was supported by NSF and CONACYT-SNI (Mexico).


[1] F. Abe *et al.*, Phys. Rev. Lett. **74**, 2626 (1995).
[2] S. Abachi *et al.*, Phys. Rev. Lett. **74**, 2632 (1995).
[3] For a recent review see: W. Marciano, "Precision electroweak measurements and the Higgs mass," arXiv:hep-ph/0411179.
[4] S. Eidelman *et al.* [Particle Data Group Collaboration], Phys. Lett. B **592**, 1 (2004).
[5] For a recent review see, *e.g.,* M. Beneke, *et al.*, "Top Quark Physics", in the Report of the 1999 CERN Workshop on SM physics at the LHC, [hep-ph/0003033].
[6] Z Hioki, arXiv:hep-ph/0407319.
[7] J.L.Diaz-Cruz,R.Martinez,M.A.Perez,A.Rosado, Phys. Rev. D**41**, 891 (1990); D. Atwood, L. Reina and A. Soni, Phys. Rev. D **55**, 3156 (1997) [arXiv:hep-ph/9609279]; J.L.Diaz-Cruz,M.A.Perez,G.Tavares-Velasco,J.J.Toscano, Phys. Rev. D **60**, 115014 (1999), [arXiv:hep-ph/9903299].
[8] F. Abe *et al.*[CDF Collaboration], Phys. Rev. Lett.**80** (1998) 2779.
[9] D. Acosta *et al.*[CDF Collaboration], Phys. Rev. Lett. **93** (2004) 142001.
[10] B. Mele, S. Petrarca, and A. Soddu Phys. Lett.**B**435, 401 (1998), [hep-ph/9805498]; J. A. Aguilar-Saavedra and G. C. Branco, Phys. Lett. B**495**, 347 (2000), [hep-ph/0004190].
[11] J. L. Diaz-Cruz and J. J. Toscano, Phys. Rev. D **62**, 116005 (2000), [arXiv:hep-ph/9910233]; E. Arganda, A. M. Curiel, M. J. Herrero and D. Temes, arXiv:hep-ph/0407302.
[12] See, for instance, reviews in "Perspectives on Supersymmetry", ed. G.L.Kane, World Scientific, 1998.
[13] For recent discussion on the THDM-III see: Diaz-Cruz,J.L. Noriega-Papaqui,R. Rosado,A. Phys. Rev. D **69**, 095002 (2004) [arXiv:hep-ph/0401194]; See also: J. L. Diaz-Cruz et al., arXiv:hep-ph/0410391.
[14] C.D.Frogatt, H.B.Nielsen Nucl. Phys. B**147**, 277 (1979).
[15] J.L.Feng, T.Moroi, H.Murayama, E.Schnapka, Phys. Rev. D **57**, 5875 (1998).
[16] I. Dorsner and S. M. Barr, Phys. Rev. D **65**, 095004 (2002) [arXiv:hep-ph/0201207].
[17] H.J.He,T.M.P.Tait, C.P.Yuan, Phys. Rev. D **62**, 011702 (2000) [arXiv:hep-ph/9911266].
[18] S. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **85**, 3999 (2000) [arXiv:hep-ex/0009001].
[19] J. L. Diaz-Cruz, JHEP **0305**, 036 (2003) [arXiv:hep-ph/0207030]; K. S. Babu and C. Kolda, Phys. Rev. Lett. **89**, 241802 (2002) [arXiv:hep-ph/0206310].
[20] J. L. Diaz-Cruz, H. J. He and C. P. Yuan, Phys. Lett. B **530**, 179 (2002) [arXiv:hep-ph/0103178].
[21] T. P. Cheng and M. Sher, Phys. Rev. D **35**, 3484 (1987).
[22] U. Cotti, L. Diaz-Cruz, C. Pagliarone, E. Vataga, in *Proc. of the APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001)* ed. N. Graf, eConf **C010630**, P102 (2001) [arXiv:hep-ph/0111236].
[23] D. Black, T. Han, H. J. He and M. Sher, Phys. Rev. D **66**, 053002 (2002) [arXiv:hep-ph/0206056].
[24] Typically, a collider experiments use cylindrical coordinate system about the beam axis $E_T \equiv Esin\theta$, $P_T \equiv Psin\theta$, $\eta \equiv -\ln\tan(\theta/2)$ and $\not{E}_{\mathrm{T}} \equiv -\sum_j E_T^j \mathbf{n_j}$, where $\mathbf{n_j}$ is the unit vector, in the azimuthal plane, that points to the $j$-th calorimeter tower.
[25] Main backgrounds are Drell-Yan ($Z^*/\gamma \to ee,\ \mu\mu$), $Z \to \tau\tau$ and $WW$ production. Other sources are processes with a real lepton and a jet or a track faking a second lepton and processes in which mismeasured muon tracks can result in an overstimate of the $\not{E}_{\mathrm{T}}$.